RESEARCH & DEVELOPMENT

Creare

Affordable Pre-Finishing of SiC for Optical Applications

Mirror Technology Days 2011

Greenbelt, MD

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Presented by:

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RESEARCH & DEVELOPMENT

Creare

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Presentation Outline

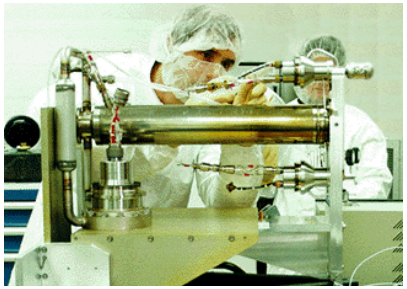
- Introduction to Creare
- Background
- Innovation
- Phase I Results
- Phase II Update
- Summary

Corporate Background

- **Founded in 1961**
- **Contract engineering R&D**
  - **Fluid dynamics and heat transfer**
  - **Cryogenics**
  - **Biomedical**
  - **Software and data systems**
  - **Sensors and controls**
  - **Advanced manufacturing**
- **Industrial and federal client base**
- **Technology commercialization**
  - **Licensing**
  - **Spin-off companies**
  - **Custom products**
- **Spinoffs**
  - **9 companies/2000 employees**
  - **Revenues $650 M/year**

Aircraft Carrier Head/Hearing Protection

Cryocooler for Hubble



Catapult Gap-Width Measurement Device

Miniature High Speed Turbine

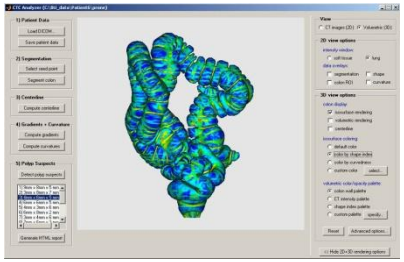


Image Reconstruction for Virtual Colonoscopy

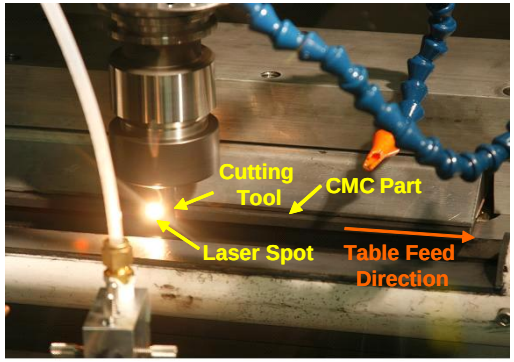
Turnkey High-Performance Data Acquisition and Processing System

Anti-Corrosion Coverings

Advanced Manufacturing at Creare

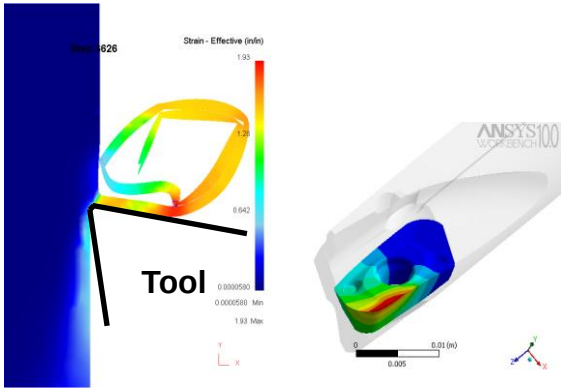
- **Focus on developing new technologies**
- **Process improvement**
  - **Cost**
  - **Quality**
- **Transition to industrial partners**

Laser-Assisted Machining



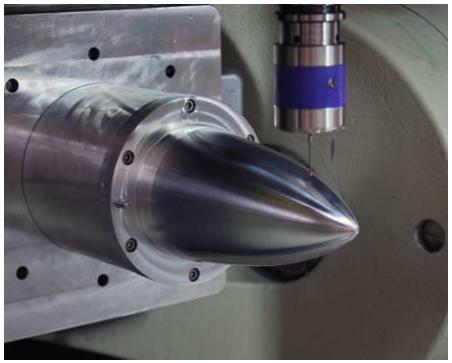
Indirect Cooling

Modeling and Simulation



Hybrid Processing for Ceramic Mirrors

On-Machine Inspection and Tool Path Correction



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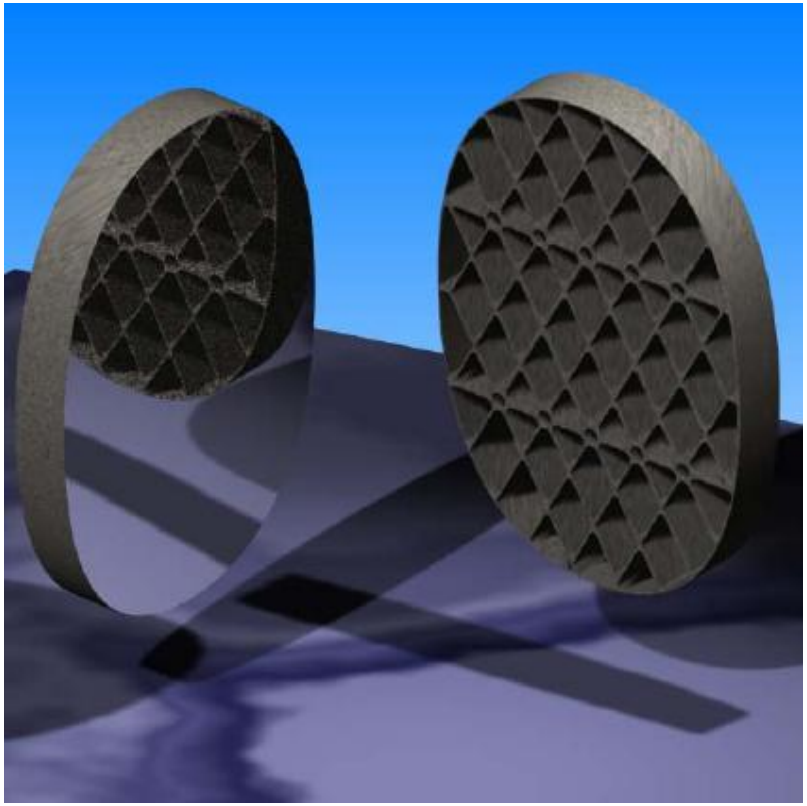
Silicon Carbide

- **Excellent candidate to replace beryllium in lightweight optics**
- **Eliminates toxicity concerns**
- **Lightweight, thermally stable**
- **Cost-effective manufacturing remains a challenge**



Overall Manufacturing Process

Sintered Part → **Pre-Finish** → **Optical Finish**

R_a	Moderate (~2 μm)	Low (~25 nm)	Very Low (~5 nm)
Accuracy	± 25 μm	± 100 nm	± 10 nm
MRR	N/A	High/Low	Low
Process	Single Step	Multiple Steps	Single Step
Cost	$$	$$$$	$$

High MRR Step

- Rapid removal
- Minimize SSD
- Accuracy ± 1 μm
- R_a ~200 nm

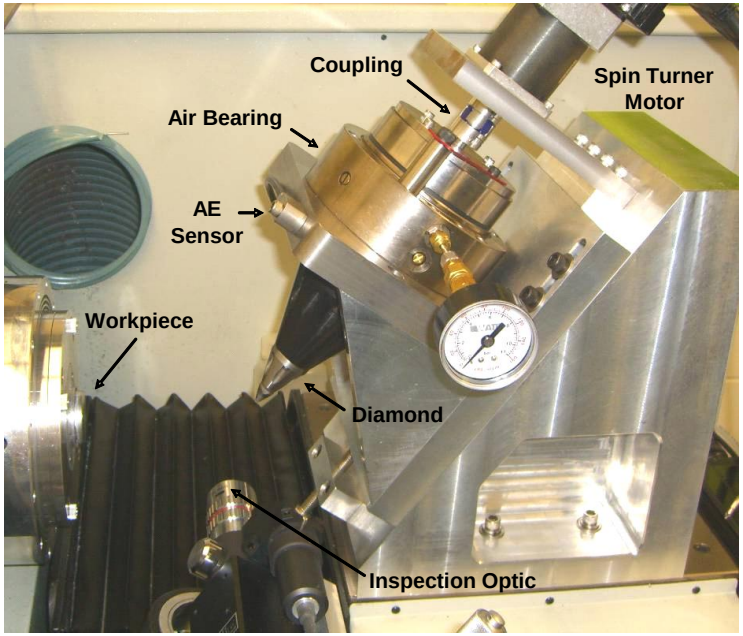
Transition

Low MRR Step

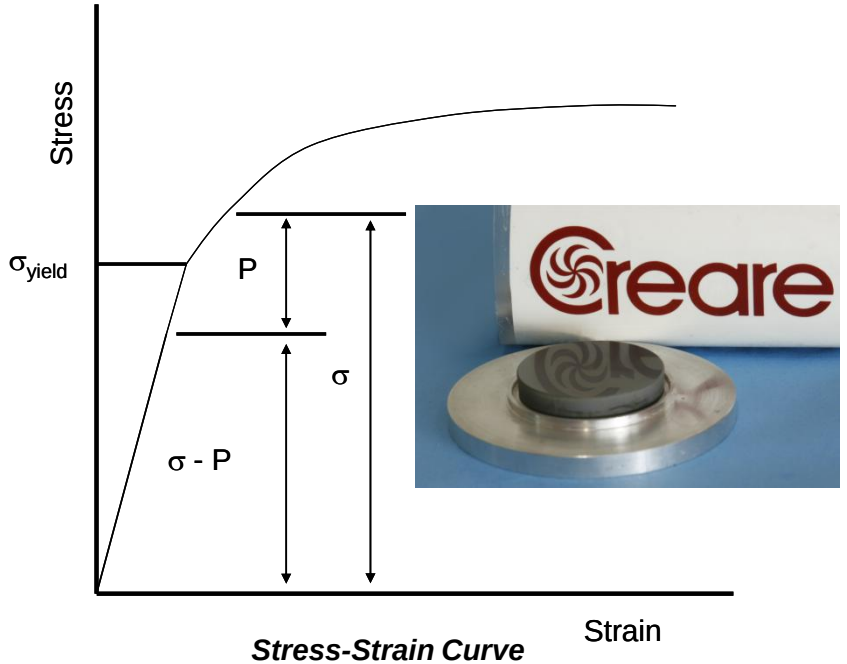
- Minimal to no SSD
- Accuracy ± 100 nm
- R_a ~25 nm

Our Hybrid Machining Approach

- Use single-point diamond turning (SPDT)
- High MRR process: spin-turning
- Low MRR process: ductile-regime machining (DRM)

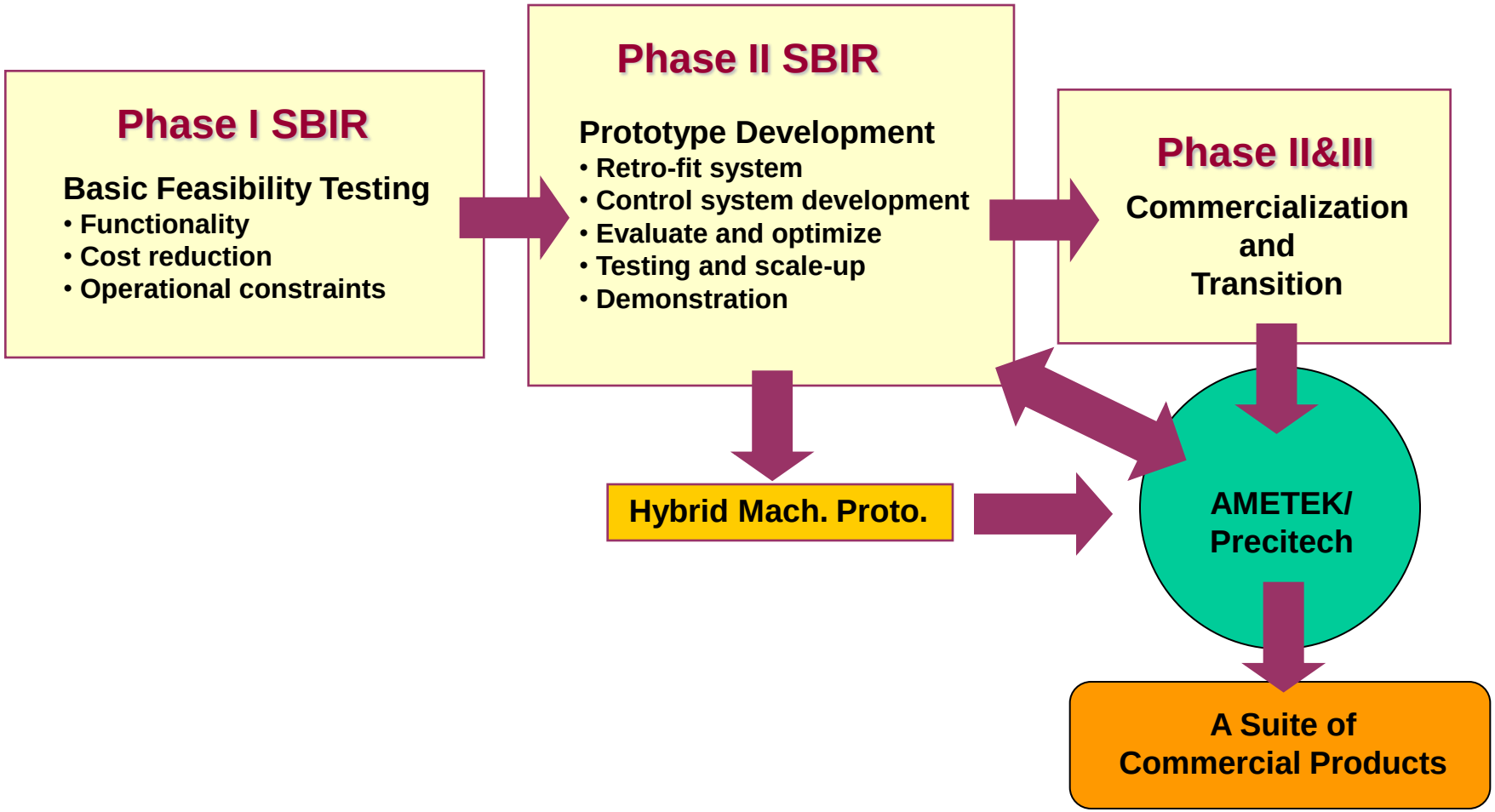


Spin Turner for High MRR Step



Stress-Strain Curve Demonstrating Low MRR DRM Process

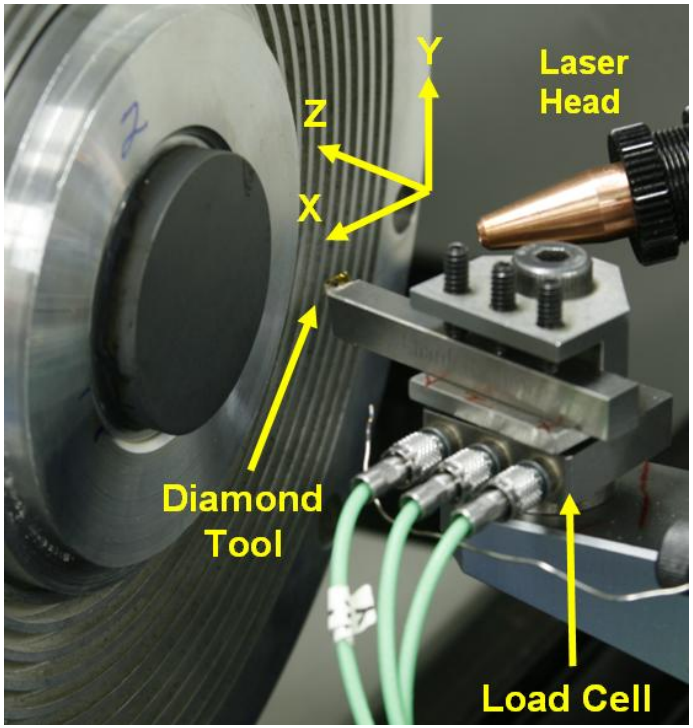
Program Overview



Phase I Results

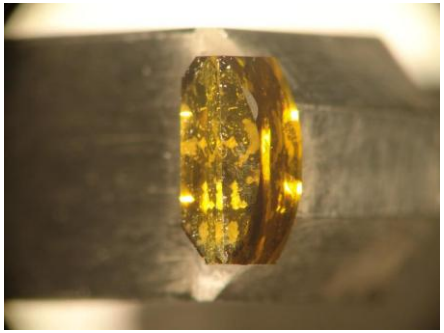
- **Demonstrated feasibility of low MRR DRM on CVD SiC**
  - **Successfully machined material to near-optical quality**
- **Demonstrated cost savings**
  - **Completed detailed cost analysis**
  - **Showed that other options are as much as 85% higher cost**
- **Developed a plan to scale up**
  - **Developed the high MRR aspect of the hybrid approach**
  - **Both based on SPDT**
  - **Sufficient to machine optics for NASA**

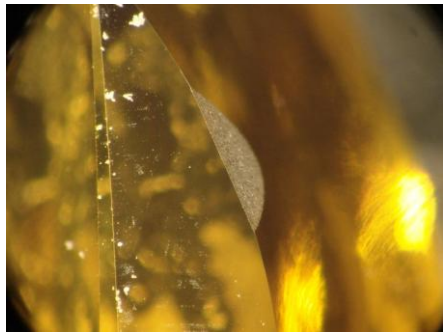
Phase I Technical Achievements



Setup for Low MRR Tests

Mirror-Like Surface Produced in CVD SiC





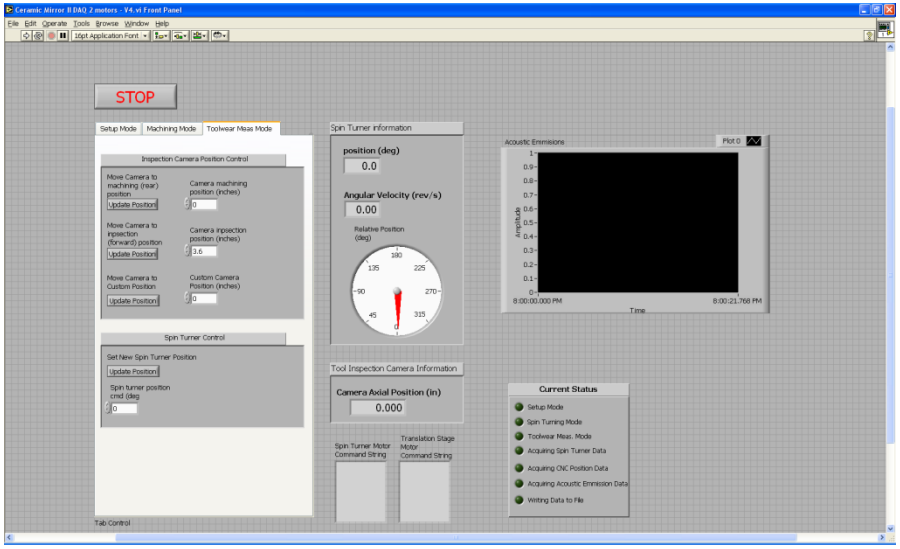
Tool Wear After ~100 Cuts

Phase II Technical Objectives

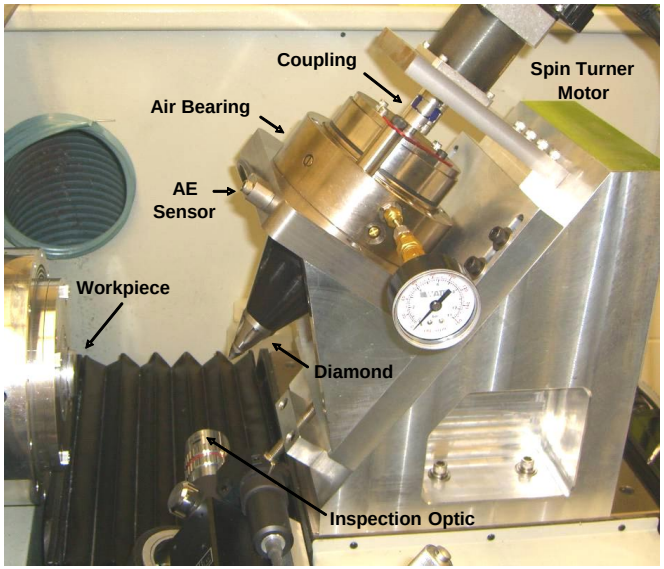
- **Optimize the hybrid machining process**
  - **Further develop high MRR process**
  - **Refine low MRR process**
- **Evaluate the performance**
  - **Coupled effects**
  - **Surface quality, part strength**
  - **Cost savings**
  - **Scale-up to larger geometries**
- **Demonstrate our approach**
  - **Machine a representative mirror (~254 mm diameter) from Trex CVD SiC and deliver to NASA**

Develop High MRR Process

- Spin turner integration
- Rotating at 1 Hz with an encoded servo-motor
- Developed mounting hardware



LABVIEW GUI



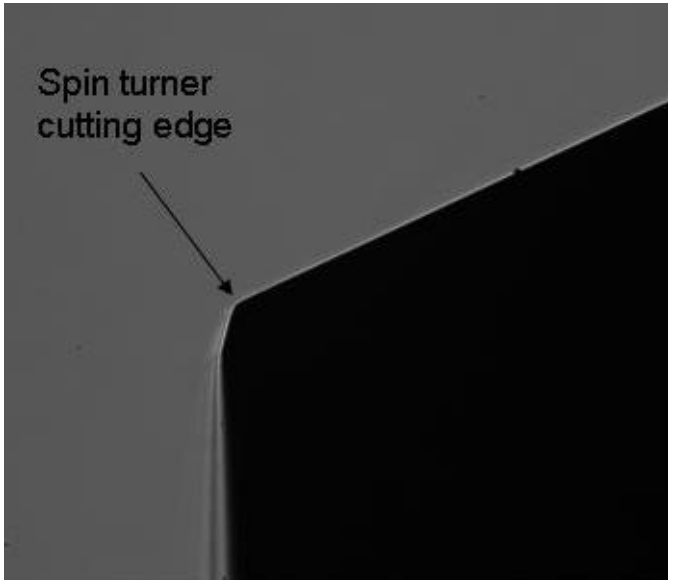
Spin Turner Integration

- Custom LABVIEW® GUI for data acquisition and system control
- Spin turner motor control
- Camera positioning, image acquisition, analysis
- Acoustic emissions data

Tool Wear Measurement

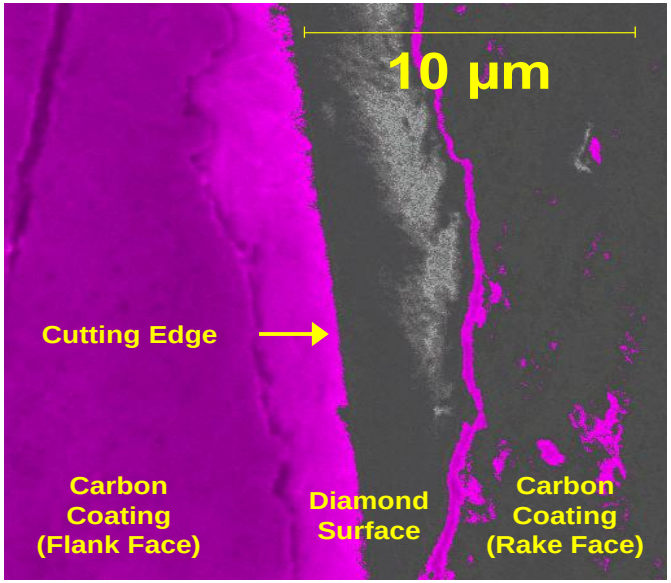
Optical

- Integrated onto precision lathe
- Prosilica GC1600 camera
- 0.9 µm resolution
- Controlled by MATLAB® GUI to photograph multiple locations after each cut



SEM

- Thin carbon coating layer on tool prevents charge buildup
- Remove carbon coating from cutting edge
- Several measurements around cutting edge



Shakedown Testing

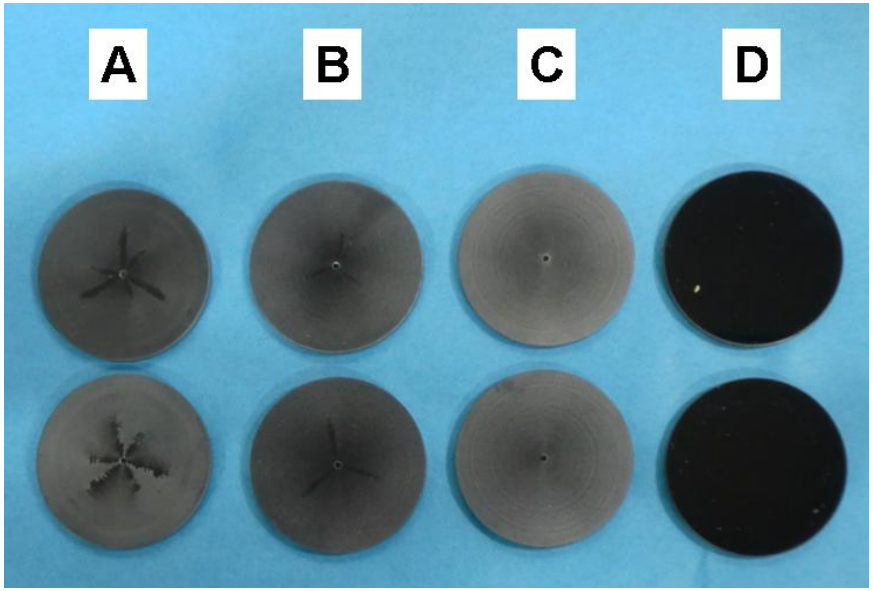
- **Single crystal silicon optics samples**
- **38 mm dia. x 3 mm thick**
- **Four optics for each condition**

Cutting Condition	Depth of Cut (µm)	Feed Rate (µm)	Undeformed Chip Thickness (µm)	Total Cutting Depth(µm)
A	3	3	0.25	36
B	6	6	0.70	36
C	12	12	2.0	36
D (uncut)	0	0	0	0

Sample Disks Appearance

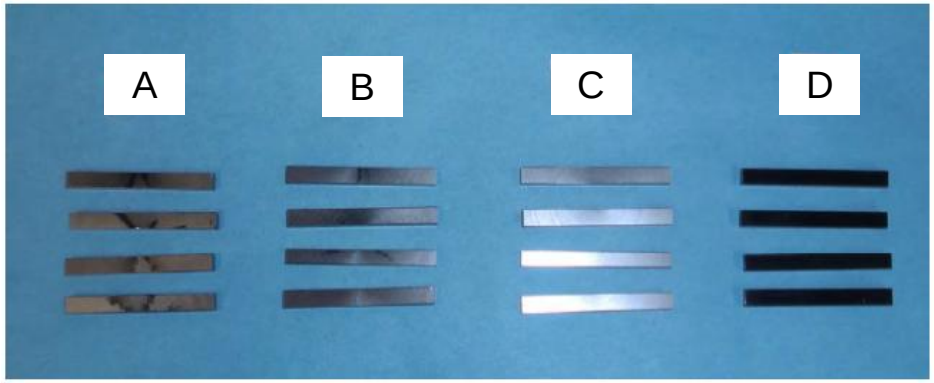
Sample Disks

- Small depth of cut cases (A, B) show clear evidence of ductile to brittle transition depending on cutting orientation



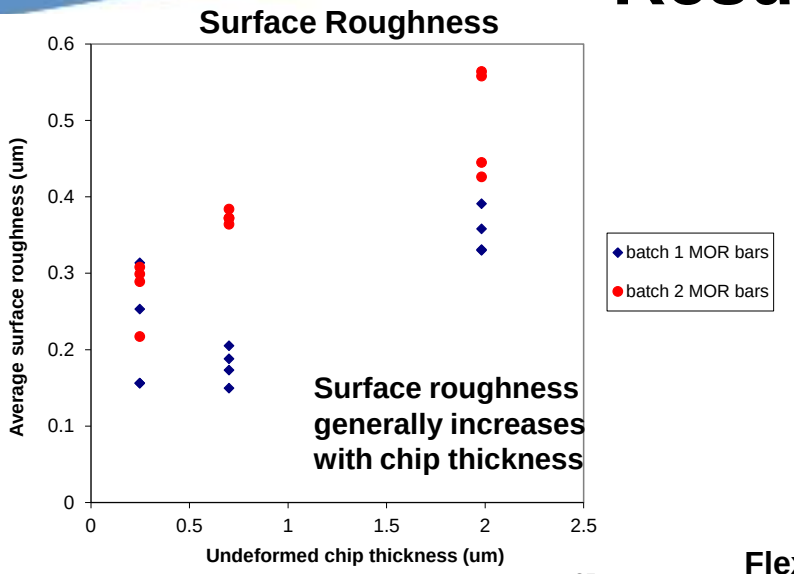
Modulus of Rupture Bars

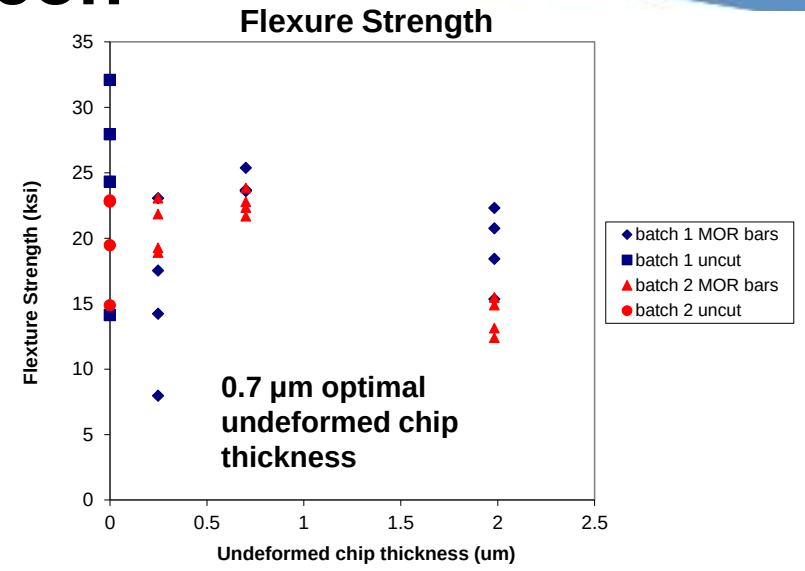
- 35 x 4 x 3 mm thick
- 2 bars per sample (32 total)
- Profilometry before strength testing

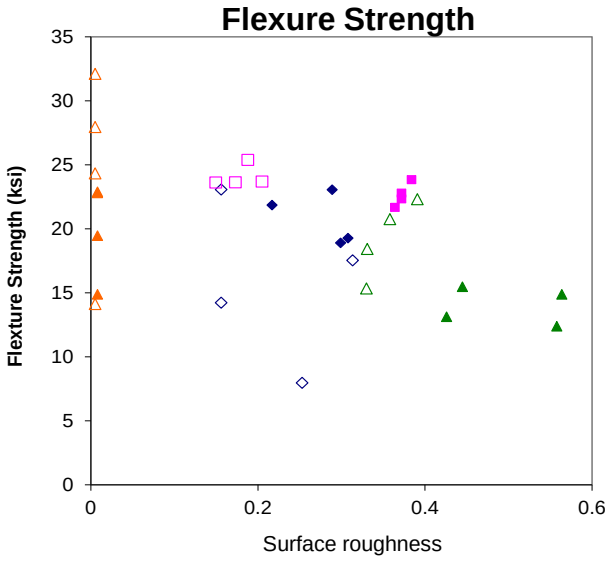


MOR Bars undergo 4-point bending failure test

Results-Silicon







General trend of decreasing strength with increasing surface roughness

Surface roughness alone insufficient to predict strength from current data

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Summary of Technical Status

- **Completed full integration and baseline testing of spin turner and tool measurement system**
- **Completed spin-turning tests of silicon and completed subsequent strength measurements**
- **Moving on to silicon carbide now**
  - **Repeat spin turning/strength tests**
  - **Refine single-point turning process**
  - **Optimize**
  - **Fabricate larger SiC mirror as final deliverable**

Case	Surface Speed (m/s)	Depth of Cut (µm)	Feed Rate (µm/rev)	Undeformed Chip Thickness (µm)	Total Number of Cuts	Total Cutting Depth (µm)
A	0.5	3	3	0.25	12	36
B	0.5	6	6	0.70	6	36
C	0.5	12	12	2.00	3	36
D	N/A	0	0	0	0	0
E	2	6	6	0.70	6	36
F	2	12	12	2.00	3	36
G	2	12	12	2.00	12	144

Questions